

Application of the NASCAP Spacecraft Simulation Tool to Investigate Electrodynamic Tether Current Collection in LEO

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Recent interest in using electrodynamic tethers (EDTs) for orbital maneuvering in Low Earth Orbit (LEO) has prompted the development of the Marshall ElectroDynamic Tether Orbit Propagator (MEDTOP) model. The model is comprised of several “modules” which address various aspects of EDT propulsion, including calculation of state vectors using a standard orbit propagator (*e.g.*, J2), an atmospheric drag model, realistic ionospheric and magnetic field models, space weather effects, and tether librations. The natural electromotive force (EMF) attained during a radially-aligned conductive tether results in electrons flowing down the tether and accumulating on the lower-altitude spacecraft. The energy that drives this EMF is sourced from the orbital energy of the system; thus, EDTs are often proposed as de-orbiting systems. However, when the current is reversed using satellite charged particle sources, then propulsion is possible. One of the most difficult challenges of the modeling effort is to ascertain the equivalent circuit between the spacecraft and the ionospheric plasma.

The present study investigates the use of the NASA Charging Analyzer Program (NASCAP) to calculate currents to and from the tethered satellites and the ionospheric plasma. NASCAP is a sophisticated set of computational tools to model the surface charging of three-dimensional (3D) spacecraft surfaces in a time-varying space environment. The model's surface is tessellated into a collection of facets, and NASCAP calculates currents and potentials for each one. Additionally, NASCAP provides for the construction of one or more nested grids to calculate space potential and time-varying electric fields. This provides for the capability to track individual particles orbits, to model charged particle wakes, and to incorporate external charged particle sources. With this study, we have developed a model of calculating currents incident onto an electrodynamic tethered satellite system, and first results are shown here.

Figures 1 and 2 show the 3D representation of the EDT system. NASCAP runs on the principle that the underlying conductors may or may not be electrically connected to each other. Thus it is possible to have an underlying series of conducting wire segments that are electrically connected to each other, but the entire tether is covered by a single insulating surface. This allows us to represent a conducting tether with a gradient in the potential along the tether (due to the motional EMF) while still insulating the tether from the surrounding plasma environment. For this run, we applied a -3500 V potential on the high-altitude satellite and a zero potential on the bottom one. The potentials of the segmented tethered elements are referenced off the -3500 V satellite and progressively downward until they meet the boundary condition of the zero-reference satellite.

Figures 3 illustrates the surface potential imposed for the simulation and the calculated surrounding space potential as a result. Note that our choice of specifying the lower-altitude satellite as a zero-potential reference essentially fixed the surface potential at the ionospheric plasma potential. This cut plane showing the space potentials essentially allows us to visualize the spacecraft's non-neutral plasma sheath, and we can see from Figure 3 that the sheath is prominent about the tether at the higher

altitudes. Because the sheath size is significantly larger than the tether diameter, this will have ramifications for non-insulating tethers, and NASCAP can be useful in precise calculations of tether current collection under those circumstances. Also note that the sheath about the upper satellite is non-symmetric along the direction of orbit propagation (i.e. along the x axis for this run). This is a natural manifestation of the charged particle wake that is prevalent in LEO due to lower mobility of the ions. This impacts the current collection behavior of the upper satellite as can be seen in Figure 4. Significantly more current is collected by the fully-conductive upper satellite on the ram side of the spacecraft relative to the wake side. NASCAP provides for detailed calculations of the severity of plasma wakes, which can be seen in Figure 5. This affects the overall ion distribution, as seen in Figure 6, and this is an important effect to be aware of, especially for planning missions in which electrostatic probes will be used to ascertain the charged particle environment both in the local region surrounding the spacecraft and the ambient ionosphere.

These preliminary runs have been done for only one environmental case: a night-time run within a quiet (i.e. non-storming) ionosphere. For the final paper to be presented at NSREC, we will have runs representative of a wide variety of environmental conditions. Additionally, we have a NASCAP model of the Space Shuttle and access to charged particle data during the Tethered Satellite System (TSS-1R) flight, allowing us to validate our model for the final paper. Finally, we will have a comprehensive literature review of the use of NASCAP for EDTs, LEO wake studies, and other example applications of the hybrid-PIC module of the NASCAP suite.

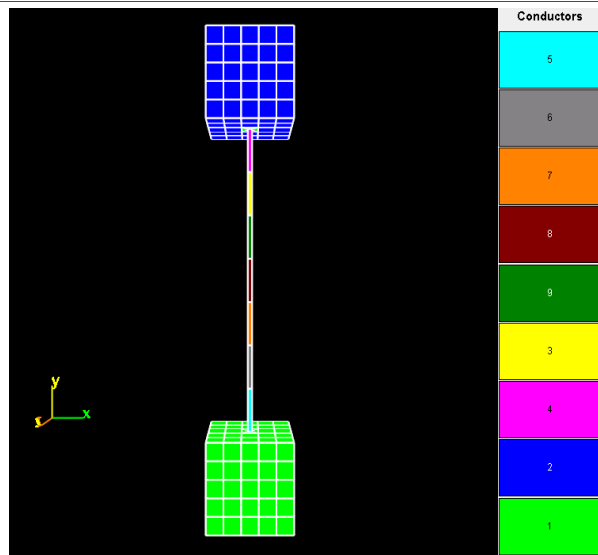


Figure 1. Geometry of the tethered satellite system with underlying conductors. The tether has been segmented to allow for a gradient in potential along the tether.

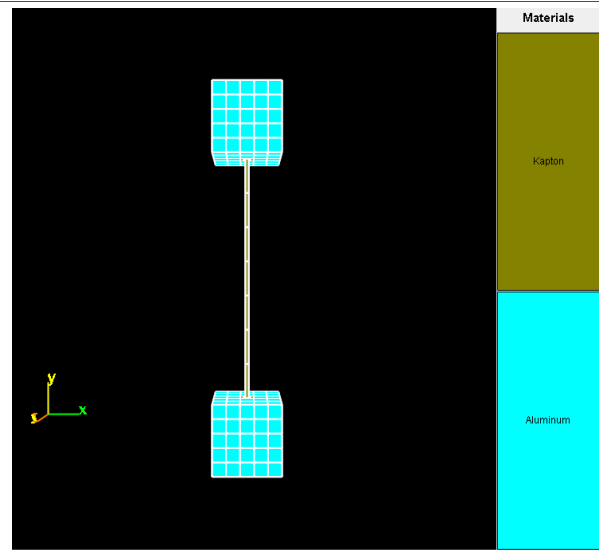


Figure 2. Surface materials of the tethered satellite system. The tether is insulated from the surrounding environment by kapton, and the only conductive surfaces are the satellites, shown here in Aluminum.

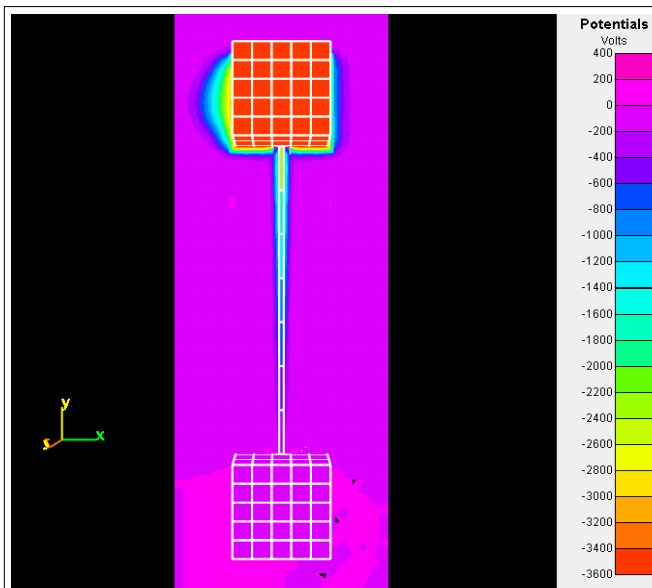


Figure 3. Surface and space potentials of the tethered satellite moving in the positive x-direction (i.e. to the right) with speed of 7.5 km/s commensurate with LEO propagation.

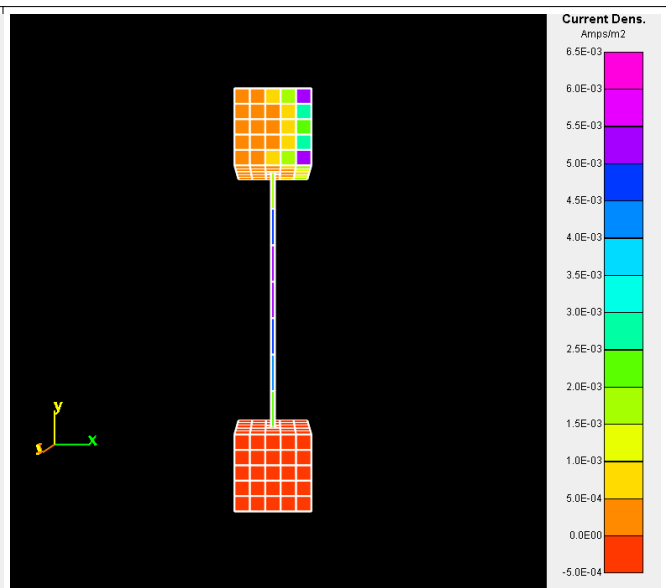


Figure 4. Ion current density incident onto the tethered spacecraft. The density is significantly increased in the ram direction. Ion current incident on the insulated tether, but this will not contribute to tether current.

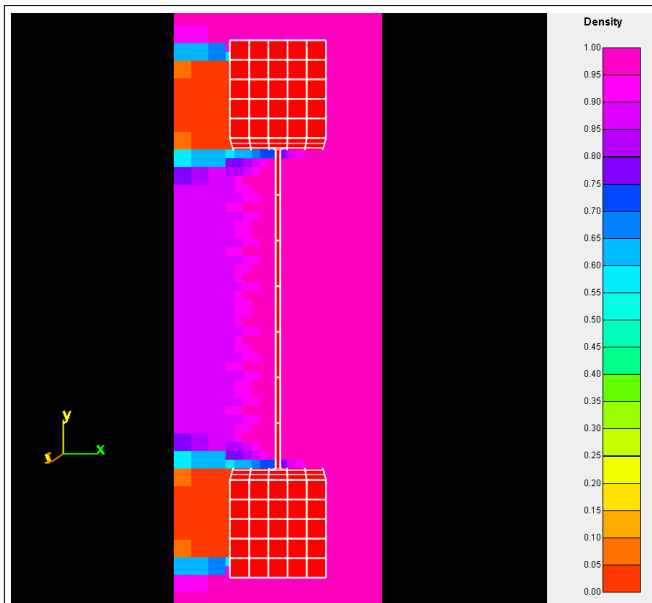


Figure 5. Ion wake due to motion in the positive x direction (i.e. to the right).

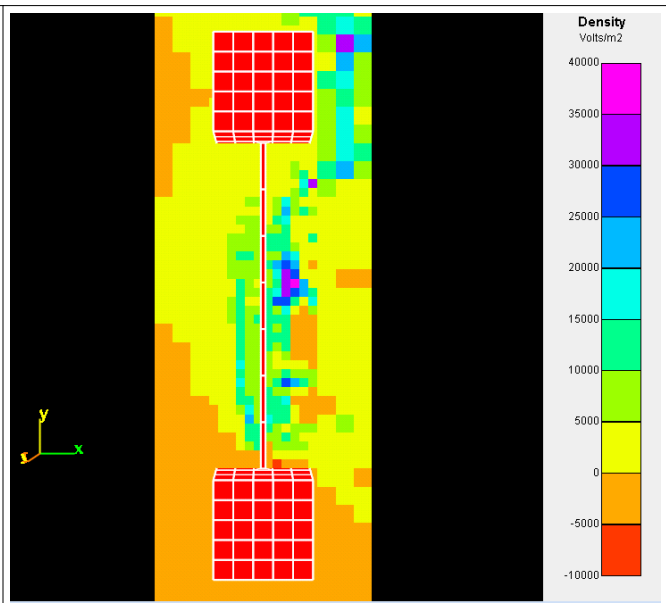


Figure 6. Hybrid-PIC simulation of the ion volume charge density for tethered satellite motion in the positive x direction (i.e. to the right)